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X-Ray and Ray Astronomy At The Turning Point

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ABSTRACT

Since 1962, approximately 40 point X-ray sources have been isolated, only about six of which have been identified with known radio or optical objects or have been studied over the 1 - 300 keV energy range. Data on the X-ray fluxes, positions, sizes and spectra of these sources have provided new information of considerable astrophysical significance and indicate that the exploratory stage of X-ray astronomy is now over. At higher energies, confirmation of a diffuse flux to 6 MeV and the successful detection of 100 MeV γ-rays from the galaxy indicate the necessity of further exploratory experiments. Satellite borne instruments on a larger scale than previously implemented will be needed to take advantage of the unique opportunity now available for advancing high-energy astrophysics.

INTRODUCTION

In the eight years since the first discovery of X-ray sources from rocket observations, X-ray astronomy has become a new and important branch of astrophysics. About forty X-ray sources have now been identified, in addition to a general or diffuse X-ray background. Although only a few of these sources have been studied extensively or have been identified with known radio or optical objects, in every case the energy radiated in the X-ray region is a factor of ten, fifty, or even a thousand times that in the radio and optical region. The understanding of cosmic objects radiating such vast amounts of energy has resulted in a new branch of knowledge known as high-energy astrophysics. Here the observations of optical, radio and X-ray astronomy are related through the processes that occur in plasmas whose temperatures are measured in hundreds of million °K, or which contain extremely relativistic electrons spiraling in the weak, tangled magnetic fields of nebulae, galaxies or even intergalactic space. In this paper we review some of the observational facts, discuss the origin of the X-ray and γ-ray emissions, and finally indicate the future development of this field.

HIGH-ENERGY ASTRONOMY

X-ray and γ-ray astronomy may be placed in perspective with respect to conventional astronomy by referring to Figure 1. This indicates the relationship between wavelength, frequency, and photon energy for the various regions of the electromagnetic spectrum. Photon energies associated with X-ray astronomy are a thousand times those associated with optical astronomy, and γ-ray photon energies may be another thousand times greater.

Also shown in Figure 1 is attenuation of the earth's atmosphere to incident electromagnetic waves. Various radio and optical "windows" have transmitted all prior information about the external universe. The infrared region is just now being explored, and new and important discoveries are being made.

At wavelengths shorter than about 3100 Å, the atmosphere becomes opaque to photons. An incident beam is attenuated to about $1/\epsilon$ of its intensity at 100 Km; therefore observations in this region require the use of rockets. The electromagnetic spectrum above 20 keV is accessible to detectors on high-flying balloons; the entire range is available to satellite instruments. Between $L\alpha$ at 1215 Å and about 1 keV, the absorption of the interstellar gas is significant; therefore, the radiations from distant objects will never be detected in this range. The energy range to approximately 20 keV is called the rocket range of X-ray astronomy, where the discoveries, identifications, and spectral measurements of X-ray sources have been made.[1] The spectrum of certain objects has been extended above 20 keV, or into the balloon range. Above 500 keV cosmic γ-rays have not yet been positively detected from point sources. This entire region is therefore still in an exploratory state.

The approximately forty sources now known have been discovered from rockets, since no satellite instrument yet flown has had comparable sensitivity. Figure 2 shows a typical rocket payload used in the discovery and location of these sources. This consists of proportional counters of several hundred cm^2 area viewing out the side of the rocket. As the rocket spins and precesses, the sensitive area, which is determined by a simple mechanical or honeycomb collimator, scans across the sky. In addition, a wire grid structure within the aperture, known as a modulation collimator,[2] causes the counting rates from strong sources to vary with the rocket motion. From these data, intensities, positions and spectra of the objects can be determined after a background counting rate correction. Typical maximum sensitivities thus far obtained in the 1 - 4 keV range are about 0.01 photons/cm^2-sec, corresponding to an intensity at the earth of 5×10^{-11} ergs/cm^2-sec.

Figure 3 summarizes present knowledge of the X-ray source locations.[3-5] The sources, when plotted in galactic coordinates, generally lie along the equator and therefore indicate association with the galaxy. Also shown are some optical and radio galactic objects; the detailed associations however are not yet clear. Only the source in Virgo is believed to be extragalactic and is associated with the strong radio emitter Virgo A (M87).[6] The source Sco XR-1, which is the strongest known galactic X-ray source at an intensity of about 10 photons/cm^2-sec, lies somewhat out of the galactic plane and apparently is closer than typical. The Crab Nebula, a well-studied optical and radio object, is located near the galactic anti-center and is about 1/10 as strong.

In addition to the discrete sources, a diffuse isotropic background of about 10^{-8} ergs/cm^2-sec-steradian at 3 keV was identified early in the history of X-ray astronomy.[7] This was soon associated with an "interstellar" γ-ray flux detected at 1 MeV by the Ranger III lunar γ-ray spectrometer.[8] The diffuse component has been most extensively studied in the 7 - 300 keV range from balloons and on the Orbiting Solar Observatory-III (OSO-III) satellite, using scintillation counters arranged in detector configurations similar to that in Figure 4. Except for the so-called 3° K radiation at millimeter wavelengths, believed due to the primordial fire ball of the "big-bang" model of the origin of the universe, no comparable phenomenon exists in the radio or optical region of the spectrum. The astrophysical and cosmological implications of the diffuse component are now being intensely investigated theoretically.

A new dimension has been added to high energy astrophysics with the discovery of positive fluxes at 100 MeV.[9] Such emissions were predicted over a decade ago and have been searched for extensively from balloons and satellites;[10] the experimental problems have been much more difficult than earlier anticipated. Two components have now been isolated, a diffuse flux similar to the X-ray background and a galactic "line" flux, which extends in a band across the sky like the Milky Way and is identified with it. Our understanding of these components is in an extremely rudimentary stage, both observationally and theoretically.

CONCEPTS IN HIGH-ENERGY ASTROPHYSICS

In addition to the origin as a discrete or diffuse source, astrophysical information is contained in the flux, angular diameter or distribution, spectrum, and polarization of the X-ray or γ-ray photons. Identification with radio or optical objects permits all the knowledge and powerful techniques of conventional astronomy to bear upon such questions as the total luminosity, density, state of ionization, magnetic field, energetic particle intensity and distribution, and energy source.

The mechanism which results in the X-ray or γ-ray production is most clearly delineated by the spectrum, i.e., the variation of photon intensity with energy.[11] Two types of spectra are clearly indicated.

1. Discrete or line spectra. These have their origin in K or L X-rays from excited atoms and in γ-rays associated with nuclear transitions. Neither has yet been discovered from cosmic X-ray sources although predictions are based upon rather solid theoretical considerations. X-rays to about 6 keV expected from O, N, Ne and Fe in hot, ionized plasmas[12] have been searched for using proportional counters.[13] Nuclear γ-rays in the 100 keV to 10 MeV range have been predicated from models of nucleosynthesis[14] or supernovae explosions which result in production of radioactive nuclides.[15] It is only a matter of sensitivity and resolution before such emissions are discovered.

2. Continuum emission. Processes producing continua include bremsstrahlung, which occurs when energetic electrons pass near atomic nuclei. These electrons may be in a highly ionized plasma and undergoing collisions so that the particles maintain a Maxwellian distribution, characterized by a temperature. To maintain ionization and to produce X-rays, the equivalent temperature of the gas must be of the order of 10 or 100 million °K. This process is believed to be responsible for the X-rays from Sco XR-1. Another bremsstrahlung process occurs when the radiating electrons have very high energies and are somewhat decoupled from the plasma in which the radiation takes place. It is not clear whether this non-thermal bremsstrahlung has yet been observed. Photons over the entire X-ray and γ-ray range could be produced by this process if the matter density-electron flux product were sufficiently high.

Another continuum process is Compton scattering, where an electron having energies of several hundred Bev may collide with an ambient photon of radio or optical energy and become scattered into the X-ray region. This mechanism may be responsible for the diffuse X-ray flux on a model in which electrons leak from radio galaxies into intergalactic space and scatter on the 3°K radiation.[16] A fourth mechanism is synchrotron radiation in which energetic electrons, also having energies of several hundred Bev, radiate in the X-ray region because of the magnetic field in which the electrons spiral. Electrons producing appreciable radiation in X-rays have short lifetimes and therefore must continuously be accelerated. X-rays from the Crab Nebula may be of synchrotron origin. The processes of synchrotron radiation and Compton scattering are related, and which one dominates the energy loss in a given medium depends upon the photon energy density compared to that of the magnetic field. A fifth mechanism which produces a broadly peaked continuum spectrum centered about 70 MeV results from the collision of cosmic rays with interstellar matter. The interaction results in a production of elementary particles called mesons, some of which decay into energetic γ-rays. The 100 MeV flux detected from the galaxy may be of this origin.

INSTRUMENTATION

The various energy ranges of X-ray astronomy are distinguished not only historically, by the mode of observation and the emission mechanisms, but also by instrumental technique. The methods are those generally used in atomic or nuclear physics but highly specialized for the weak flux and high background situation of astronomy. Generally, these detectors produce an electrical signal, called an event, for each detected photon. The event is counted or pulse-height analyzed to obtain energy information.

1. 0.25 - 10 keV. This is the region in which proportional counter technique is used. The energy range is determined by the window material, thickness and filling gas. By doing a careful pulse-height analysis, an energy resolution of about 20 per cent at 6 keV may be obtained. Proportional counters are typically large area devices with the collimation properties determined by a mechanical collimator which permits source locations to within several tenths of a degree. Locations to several arc minutes have been obtained using the modulation collimator in front of the aperture as shown in Figure 2. A device known as a proportional chamber has been recently developed which consists of a large number of elemental proportional counters sharing a common gas volume.

In this energy range the technique most analogous to optical astronomy, that of the focusing X-ray telescope,[1] may be used. X-rays incident at grazing incidence upon a particular combination of surfaces are focused as shown in Figure 5. At small angles, reflection occurs at energies up to several keV when scattering dominates. Although this particular device has not yet produced definitive observations on cosmic X-ray sources, its potential to determine the X-ray source structure and size is clear. Furthermore, instruments such as Bragg spectrometers and polarimeters may be placed at the focus of such a device since it functions as a large area collector much like an ordinary telescope.

2. 10 - 300 keV. This is the range where balloon exploration of point sources has been accomplished.[17] The principle technique has been that of the shielded NaI scintillation counter. Devices considerably more sophisticated than that of Figure 4 and having areas up to 400 cm^2 have now been flown on balloons.[18] Typical energy resolution of 20 per cent at 50 keV and angular resolutions of a few degrees are practical. This device, like the proportional counter, has no imaging properties and counts every photon entering the aperture.

The balloon payload used at UCSD for recent observations is shown in Figure 6.[19] A 10-million cubic foot balloon carries the 700-pound payload suspended through a parachute to about 135,000 ft. The base contains batteries, telemetry, command receivers and programmers. Detectors are mounted in a declination/right ascension axis in the upper structure. The polar axis is oriented North using the earth's field and a startracker and is commanded to provide a series of drift scans across the object, collecting background before and after each observation. The detector used, shown in Figure 7, is an advanced version of the OSO-III detector. Large area and small collimation angles are provided by the honeycomb collimator whose phototubes are connected in electrical anti-coincidence with the central detector. In addition to providing attenuation of X-rays from outside the sensitive aperture, such a detector rejects background due to higher energy cosmic ray and photon interactions in the shield.

3. 0.3 - 10 MeV. Scintillation counters similar to that used at lower energies but having much thicker shields and larger volumes because of the longer photon range will be used here. There are now being implemented from balloons in order to extend the spectrum of discrete sources to higher energies. The 10 keV to 10 MeV range will see the application of the cooled Lithium-drifted Germanium, detector, Ge (Li),[20] in searching for γ-ray line emissions where extreme energy resolution, a few keV at 1 MeV, is necessary.

4. >10 MeV. At 100 MeV, the discovery of the diffuse and galactic component was made with a rather complex combination of scintillation and Cerenkov counters which used pair production as the primary interaction for detection.[9] For the future, however, the spark chamber[21] holds the most promise and is being highly developed for γ-ray astronomy. Because of the large amount of production in the overlying atmosphere, observations at 100 MeV have thus far not proved fruitful from balloons.

POINT SOURCES

1. The Crab Nebula. The Crab Nebula, which resulted from a supernova explosion in the year 1054, was the first known optical or radio object identified with an X-ray source. After early exploration indicated X-ray emission of about 1 photon/cm^2-sec from a region within a few degrees of the Crab Nebula, the precise identification was made by the Naval Research Laboratory (NRL) during the 1964 lunar occultation.[22] Figure 8 shows the nebula superposed on the rocket scans which provided identification. The counting rate decreased slowly as the moon's edge moved across the nebula, which indicated that the emission took place from an extended region of the nebula rather than from a small object in the center, a most important discovery at that time. The identification and size was verified by scientists at American Science and Engineering (ASE) and MIT in 1966.[23]

The signature of the emission process is the spectrum. Although rocket observations obtained the spectrum to about 15 keV, extension to higher energies has been made from balloon-borne scintillation counters and has a power law form[24] as shown in Figure 9. This is indicative of a synchrotron process which, if true, poses a considerable problem because of the short lifetime of the electrons in the 10^{-4} Gauss field of the Crab Nebula. This implies the electrons are more or less continuously injected or accelerated to over 100 Bev.

Astrophysicists' ideas about processes in the Crab Nebula have undergone a remarkable revolution the past year with the discovery that about 10 per cent of the X-rays emitted occur in bursts or pulses. The discovery of pulsating radio objects (pulsars) having periods of about a second has been an important recent discovery in radio astronomy. The identification of a pulsed radio component in the Crab Nebula at the very high rate of 30 Hz was soon followed by the discovery that the optical emission from a starlike object at the center of the nebula was also pulsed. Subsequent investigation proved the pulsed radio, optical and X-ray components all have the same phase.[25]

The present concept of a pulsar is that of a rotating neutron star, about one solar mass, which became condensed into solid nuclear material and whose radius is about 10 km. An asymmetry in such a rotating object can produce a pulsed emission. Although a detailed mechanism has not been completely worked out, the energy seems to come from slowing down of the rotation. The search for other pulsar X-ray emitters seems a particularly important observational objective.

2. Sco XR-1. This source was not easily associated with any unique optical or radio object. The position obtained with the modulation collimator of Figure 2 was located within one of the small error squares shown on the star field picture of Figure 10.[26] The source was associated with a 13th magnitude blue flickering optical object.

Soon after its discovery the spectrum of Scorpius XR-1, as measured from rockets and balloons, was found to have the emission characteristics of a hot ionized plasma. The spectrum has now been extended beyond 50 keV and has been observed in the radio and the infrared. Figure 11 shows the flux measurements over the entire range, and a solid line shows the radiation expected from an ionized gas at 50×10^6 °K, transparent to its own radiation. Present measurements imply that the object radiates like a blackbody in the infrared region and therefore also at longer wavelengths. The radio emission must be due to another process. Based on a distance estimation of 500 light-years, and using the data of Figure 11 with a thermal bremsstrahlung mode for the emission, Sco XR-1 has a diameter of about 10^8 cm and a density of about 10^{15} cm^{-3}.

One of the unusual properties of Sco XR-1 is the time variation of the optical flux measured by ground-based telescopes.[27] As shown in Figure 12, there are three distinct variations: a flickering which occurs in a few minutes' period, a slow variation of approximately one magnitude (a factor of 2.5) over several hours and occasional short flare-like events. Correlations between optical and X-ray variations will indicate coupling between the processes or the source regions which produced the emission. Simultaneous observations are just now beginning.[28] Figure 13 shows the X-ray emission measured on the OSO-III and a simultaneous observation made on a Mount Wilson telescope.[29] Clearly, increases in the X-ray and optical emission are coupled. The complete significance of these flares and their implication for dynamical models of Scorpius is not understood.

3. Other sources. The remaining X-ray sources are less studied. Some, such as Cyg X-2 and Cyg X-3 have a bremsstrahlung spectrum similar to the Crab Nebula.[30] The sources clustered near

the galactic center have not been sufficiently well resolved so definitive spectral measurements are available over a wide energy range. Many sources are now classified simply as having a "hard" or "soft" X-ray spectrum.(3)

Centaurus XR-2 has nova-like behavior in that it abruptly appeared in early 1967 and decreased in intensity with a one-month time constant.(31) Later balloon observations indicated a hard spectrum extending up to approximately 100 keV, while being unobservable in the rocket X-ray range. Other sources have also been reported to have appeared suddenly or to have significant time variations.

The study of point X-ray sources is just now beginning; the identification and study of a hundred objects will require higher sensitivity, longer observing times and correlated ground-based observations.

THE DIFFUSE COMPONENT

The compendium of observations of the diffuse spectrum shown in Figure 14 covers a wide range of energies and intensities. The 1 - 20 keV spectrum has been determined by rocket borne proportional counters.(32) At higher energies, observations on balloons(33) and the Ranger III(8) contributed the early data. Since these results indicated the flux was isotropic to within about 10 per cent and the galaxy is transparent to these X- and γ-rays, an extragalactic orgin is required. Two possibilities have been advanced, a) scattering by relativistic intergalactic electrons on the 3°K radiation or b) the effect of the X-ray emission from many galaxies integrated to a Hubble distance (the radius of the observable Universe.

Recent observations of this flux have been made on the OSO-III satellite,(34) shown in Figure 15. Although this NASA satellite series is designed to carry telescopes stabilized to about one arc minute which measure solar UV and soft X-ray emissions, the rotating gyro wheel usually contains a number of X-ray and γ-ray instruments. The OSO-III carried the UCSD X-ray telescope shown in Figure 4 and the MIT 100 MeV γ-ray detector. In the lower energy range, the OSO-III has confirmed the existance of a "break" in the power law spectrum at about 40 keV which may be interpreted in terms of the electron lifetime in intergalactic space if the Compton mechanism is responsible for the emission.(16) Furthermore, this component has been measured to be isotropic within 1 per cent or so over the entire celestial sphere,(34) when proper account is taken of the point sources and emission from the galaxy itself. This high isotropy poses constraints upon cosmological models associated with the "big bang" origin of the universe.

As already indicated, two components in the 100 MeV region have been identified, a) the isotropic flux shown as a single point in Figure 14 and b) an additional component associated with the plane of the galaxy. The high flux has caused considerable speculation regarding the galactic cosmic ray and magnetic field intensity and the density of the interstellar medium.

The 1 - 10 MeV intermediate region is in a more exploratory stage. The integrated spectrum has been measured on the Ranger-III and by a small satellite, the ERS-18,(35) with simple isotropic scintillation counters such as that shown in Figure 16. As shown in Figure 14, these data tend to indicate an additional component above that associated with the extrapolation of the diffuse component to higher energies.(36) Since nothing is known about the isotropy of 110 MeV γ-rays, determining their origin to be galactic or extragalactic is an important question at this time.

At extremely low energies, 0.25 keV, a number of important observations have also been made recently.(37) Low energy X-rays of extragalactic origin are absorbed by interstellar matter and provide a measure of the amount of galactic material along a line of sight at various galactic latitudes. Further exploration in this region may also indicate new galactic sources.

THE FUTURE

As can be determined from this review, the exploratory stage of X-ray astronomy is over. Measurements on large numbers of sources with better spectral and angular resolution are required. Increasing sensitivity a factor of 10 to 10^{-3} photons/cm^2-sec should increase the number of detected sources to perhaps 100. If their locations were known to a few tenths of a degree, many identifications should be possible. Such instruments are now being constructed and will be flown on the Small Astronomy Satellite (SAS) in 1970, and on the OSO-H in 1971. The SAS and OSO series will continue to provide a platform for X-ray observations and for instruments designed for exploration at higher energies, where the recent detection of positive fluxes has given new impetus to this work.

Much larger devices will eventually be required to continue advancing in these fields. Accordingly, NASA is sponsoring a large satellite, the High Energy Astronomical Observatory (HEAO), shown in Figure 17. Designed to accommodate a very large area proportional counter which will have a sensitivity of 10^{-6} photons/cm^2-sec, the satellite also contains large cosmic-ray and γ-ray spark chambers and medium energy γ-ray instruments of considerable area. The HEAO is designed to rotate about its spin axis and, therefore, will slowly sweep across the sky. Figure 18 shows a possible follow-on HEAO designed for specific observations of discrete sources. This concept includes a focusing X-ray telescope for imaging weak sources and a large area collector which provides high intensities for high resolution spectrometers. This version of the HEAO must be stabilized in the direction of the source.

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REFERENCES

(1) Giaconni, R. and H. Gursky, "Observation of X-ray Sources Outside the Solar System," Space Science Reviews, IV 2, 151-175 (1965).

(2) Bradt, H., G. Garmire, M. Oda, G. Spada, and B. V. Sreekantan, "The Modulation Collimator in X-ray Astronomy," Space Science Reviews 8, 471-506 (1968).

(3) Friedman, H., E. T. Byram, and T. A. Chubb, "Distribution and Variability of Cosmic X-ray Sources," Science 156, 3733, 374-378 (1967).

(4) Giaconni, R., P. Gorenstein, H. Gursky, and J. R. Waters, "An X-ray Survey of the Cygnus Region," Ap. J. 148, Part 2, L119 (1967).

(5) Gursky, H., P. Gorenstein, and R. Giaconni, "The Distribution of Galactic X-ray Sources from Scorpio to Cygnus," Ap. J. 150, L75-L84 (1967).

(6) Bradt, H., W. Mayer, S. Naranan, S. Rappaport, and G. Spada, "Evidence for X-radiation from the Radio Galaxy M87," Ap. J. 150, L199-L206 (1967).

(7) Bowyer, S., E. T. Byram, T. A. Chubb, and H. Friedman, Nature 201, 1307 (1964).

(8) Arnold, J. R., E. C. Anderson, A. E. Metzger, and M. A. Van Dilla, "Detection of an Interstellar Flux of Gamma-Rays," Nature 204, 766-767 (1964).

(9) Clark, G. W., G. P. Garmire, and W. L. Kraushaar, "Observation of High-Energy Cosmic Gamma Rays," Ap. J. 153, L203-L207 (1968).

(10) Garmire, G. and W. L. Kraushaar, "High Energy Cosmic Gamma Rays," Space Science Reviews 4, 123-146 (1965).

(11) Gould, R. J., "Origin of Cosmic X-rays," Am. J. Phys. 35, 376-393 (1967).

(12) Tucker, W. H. and R. J. Gould, "Radiation from a Low Density Plasma at 10^6 - 10^8 K," Ap. J. 144, 244-258 (1966).

(13) Holt, S. S., E. A. Boldt, and P. J. Serlemitsos, "Iron Line Emission from X-ray Sources," Ap. J. Letters 154, L137-L140 (1968).

(14) Clayton, D. D. and J. Silk, "Measuring the Rate of Nucleosynthesis with a Gamma-Ray Detector," Ap. J. 158, L43-L48 (1969).

(15) Clayton, D. D. and W. L. Craddock, "Radioactivity in Supernova Remnants," Ap. J. 142, 189 (1965).

(16) Brecher, K. and P. Morrison, "Leakage Electrons from Normal Galaxies: The Diffuse Cosmic X-Ray Source," Phys. Rev. Letters 23, 14, 802-803 (1969).

(17) Peterson, L. E., R. L. Jerde, and A. S. Jacoabon, "Balloon X-ray Astronomy," AIAA J. 5, 1921-1927 (1967).

(18) Lewin, W. H., G. W. Clark, and W. B. Smith, "Sky Survey of High-Energy Cosmic X-Rays and Spectral Information on Sources in the Crab Nebula, Cygnus, and Scorpius," Can. J. Phys. 46, S409-13 (1968).

(19) Peterson, L. E., "Properties of Individual X-Ray Sources," UCSD-SP-69-06 (July 1969).

(20) Jacobson, A. S., "A Search for Gamma-Ray Line Emissions from the Crab Nebula," Ph. D. Thesis, Univ. of Calif., San Diego (1968).

(21) Fichtel, C. E., D. A. Kniffen, and H. B. Ogelman, "Results of Gamma-Ray Balloon Astronomy," Ap. J. 158, 193-206 (1969).

(22) Bowyer, S., E. T. Byram, T. A. Chubb, H. Friedman, "Lunar Occultation of X-ray Emission from the Crab Nebula," Science 146, 912-917 (1964).

(23) Oda, M., H. Bradt, G. Garmire, G. Spada, B. V. Sreekantan, H. Gursky, R. Giaconni, and P. Gorenstein, "The Size and Position of the X-ray Source in the Crab Nebula," Ap. J. Letters 148, 5, (1967).

(24) Peterson, L. E., A. S. Jacobson, R. M. Pelling, and D. A. Schwartz, "Observations of Cosmic X-Ray Sources in the 10-250 keV Range," Can. J. Phys. 46, S437 (1968).

(25) Bradt, H., S. Rappaport, W. Mayer, R. E. Nather, B. Warner, M. Macfarlane, and J. Kristian, "X-Ray and Optical Observations of the Pulsar NP 0532 in the Crab Nebula," Nature 222, 728-730 (1969).

(26) Gursky, H., et al., "A Measurement of the Location of the X-Ray Source Sco X-1," Ap. J. 146, 310-316 (1966).

(27) Mook, D. E., "UBV Photometry of Sco XR-1," Ap. J. 150, L25-L30 (1967).

(28) Mark, H., R. E. Price, R. Rodrigues, F. D. Seward, and C. D. Swift, "Further Simultaneous Observations of the Optical and X-Ray Spectra of Sco X-1," Ap. J. Letters 156, L67-L72 (1969).

(29) Hudson, H. S., L. E. Peterson, and D. A. Schwartz, "Simultaneous X-Ray and Optical Observations of Sco X-1 Flares," Ap. J. 159, L51-L55 (1970).

(30) Gorenstein, P., R. Giaconni, and H. Gursky, "The Spectra of Several X-Ray Sources in Cygnus and Scorpio," Ap. J. 150, L85-L97 (1967).

(31) Chodil, G., H. Mark, R. Rodrigues, and C. D. Swift, "Nova-Like Behavior of the X-ray Source Centaurus XR-2," Ap. J. Letters 152, L45-L53 (1968).

(32) Boldt, E. A., D. Upendra, and S. G. Holt, "2-20 keV Spectrum of X-Rays from the Crab Nebula and the Diffuse Background Near Galactic Anticenter," Ap. J. 156, 427-436 (1969).

(33) Bleeker, J. A. M. and A. J. M. Deerenberg, "The Diffuse Cosmic X-Ray Background from 20 to 220 keV," Ap. J. 159, 215-228 (1970).

(34) Schwartz, D. A., "The Spatial Distribution of the Diffuse Component of Cosmic X-Rays," Ph. D. Thesis, Univ. of Calif., San Diego (1969).

(35) Vette, J. I., J. L. Matteson, D. Gruber, and L. E. Peterson, "The Cosmic Gamma Ray Spectrum Near One MeV Observed by the ERS-18 Satellite," IAU Symposium No. 37, Rome Italy, May, 1969 (in press).

(36) Stecker, F., "Possible Initial Evidence of Extragalactic Cosmic-Ray Protons and the Age of Extragalactic Cosmic-Ray Sources," Nature, 224, 870 (1969).

(37) Bunner, A. N., P. C. Coleman, W. L. Kraushaar, D. McCammon, T. M. Palmieri, A Shilipsky, and M. Ulmer, "Soft X-Ray Background Flux," Nature 223, 1222 (1969).

BIBLIOGRAPHY

Gould, R. J. and G. R. Burbidge, "High Energy Cosmic Photons and Neutrons," Handbuch der Physik, Vol. 46, Part 2, 1966.

Position Paper of the Astronomy Missions Board, A Long-Range Program in Space Astronomy (ed., R. O. Doyle) NASA, July 1969.

Proceedings of the 37th IAU Symposium on X- and Gamma-Ray Astronomy (D. Reidel Publishing Co., The Netherlands; ed., Gratton), in press.

ILLUSTRATIONS

Figure 1. The Astronomical Electromagnetic Spectrum. In addition to showing the relation between wavelength, frequency, and energy, this graph shows the attenuation imposed by the earth's atmosphere on incident photons.

Figure 2. A Typical Rocket Payload. Each proportional counter views through a wire grid structure known as modulation collimator which permits precise location of the source. Courtesy of American Science and Engineering (ASE)

Figure 3. X-Ray Source Positions. These were determined by Naval Research Laboratory (NRL) and ASE Surveys and are plotted in galactic coordinates to compare with other galactic objects.

Figure 4. A Scintillation Counter X-Ray Telescope. This was flown by UCSD on balloons and on the OSO-III satellite and operates over the 7 - 200 keV range. The collimator phototube provides an electrical veto for background events.

Figure 5. A Focusing X-Ray Telescope. This provides collection and imaging for photons below about 5 keV. Devices such as image tubes, Bragg spectrometers, and polarimeters may be placed at the focus in future missions.

Figure 6. A Balloon Payload. This is used at UCSD for spectral and time variation studies of X-ray sources. The 700-pound gondola is hung through a parachute from a 10-million cu. ft. balloon.

Figure 7. An Updated X-Ray Telescope. This operates between 10 and 500 keV and is used in the balloon gondola of Figure 6. A similar version is under construction for the 1971 Orbiting Solar Observatory.

Figure 8. The Crab Nebula. Various rocket scans have shown the X-ray emission occurs over the large region indicated by the dotted circle.

Figure 9. The Spectrum of the Crab Nebula. Many rocket and balloon observations have provided this data. The power law spectrum is believed to indicate a synchrotron process.

Figure 10. The Location of Sco XR-1. After the position determinations were obtained from a rocket flight, the 13^m optical object indicated was identified as the X-ray emitter.

Figure 11. Total Spectrum of Sco XR-1. Interpretation of this data in terms of known emission mechanisms suggests a hot ionized plasma at about 50 million °K.

Figure 12. Optical Variation of Sco XR-1. The correlations of these variations with changes in the X-ray flux are now being studied extensively.

Figure 13. A Sco XR-1 Flare. The simultaneous X-ray and optical effects indicate the importance of obtaining ground-based telescope time during X-ray astronomy missions.

Figure 14. The Spectrum of Diffuse Cosmic X-Rays. These data have been compiled from many rocket, balloon and satellite observations. The flux may originate from Compton scattering by energetic electrons in intergalactic space.

Figure 15. The OSO-III Satellite. This carried in its rotating wheel section two instruments which provided new data on the spectrum and isotropy of diffuse cosmic X-rays and γ-rays.

Figure 16. An Isotropic γ-Ray Spectrometer. These simple detectors were used on the Ranger III and the ERS-18 to determine the spectrum from 0.1 to 6.0 MeV. Further study in this range will require directional detectors.

Figure 17. The High-Energy Astronomy Observatory. Proposed for launch in 1975, this spin-stabilized satellite will carry large area proportional counters, high-energy γ-ray detectors, and spark chambers designed for survey work.

Figure 18. A Three-Axis Stabilized HEAO. This will provide a platform for focusing X-ray telescopes, with specialized detection equipment for detailed studies of discrete sources.

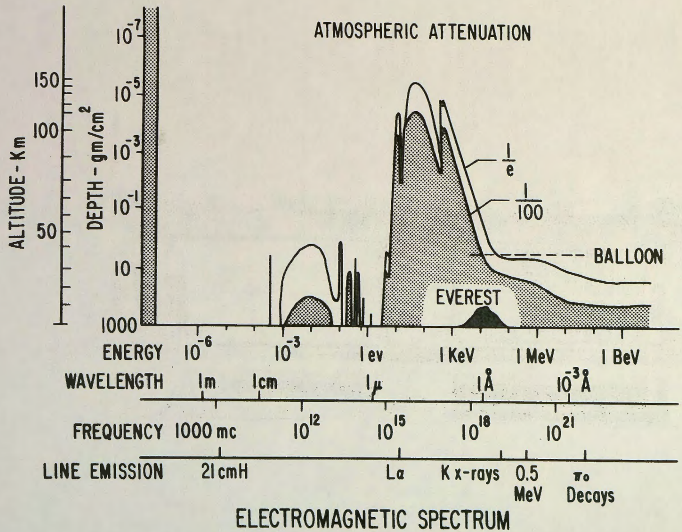


Figure 1. The Astronomical Electromagnetic Spectrum.

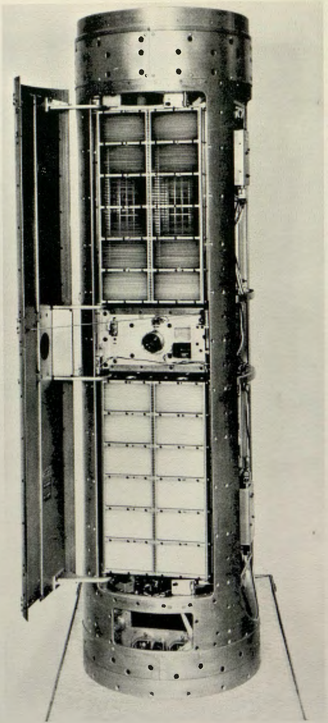
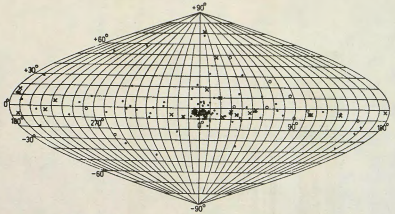
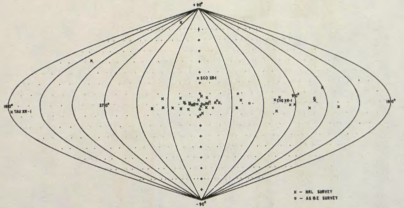


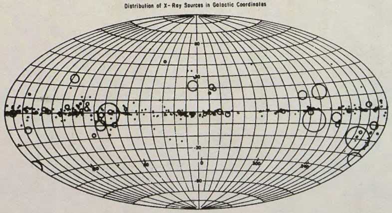
Figure 2. A Typical Rocket Payload



The distribution of novae in the sky. New galactic coordinates l^{II}, b^{II} are used. Circles: $m_{max} < 3.0$; crosses: $3.0 \leq m_{max} < 6.0$; dots: $6.0 \leq m_{max}$.

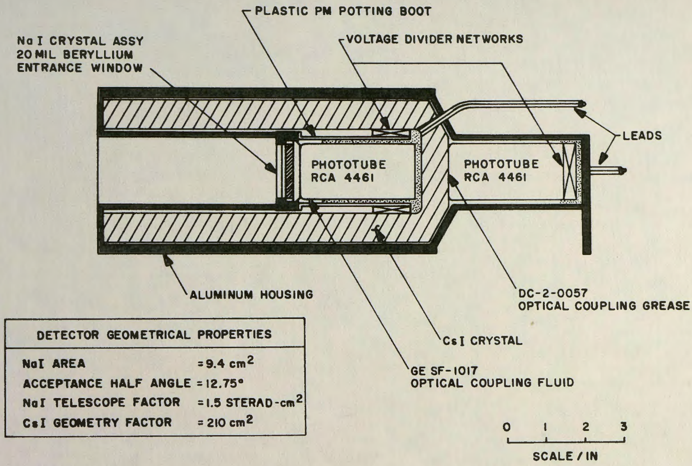


Distribution of X-Ray Sources in Galactic Coordinates



The distribution of H II regions in galactic coordinates. New longitudes are indicated.

Figure 3. X-Ray Source Positions.



DETECTOR GEOMETRICAL PROPERTIES	
NaI AREA	= 9.4 cm^2
ACCEPTANCE HALF ANGLE	= 12.75°
NaI TELESCOPE FACTOR	= 1.5 STERAD-cm^2
CsI GEOMETRY FACTOR	= 210 cm^2

Figure 4. A Scintillation Counter X-Ray Telescope.

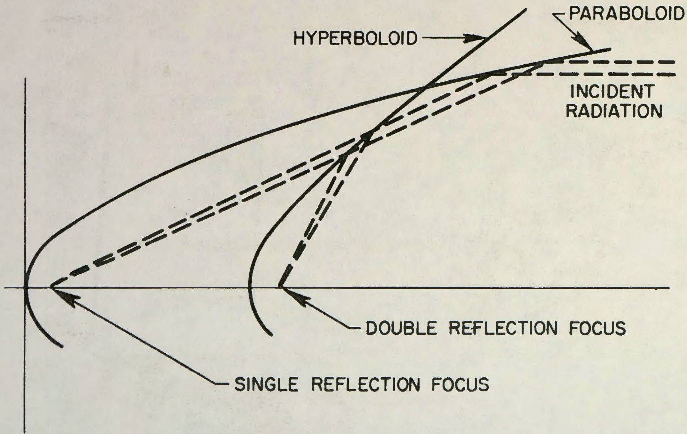


Figure 5. A Focusing X-Ray Telescope.

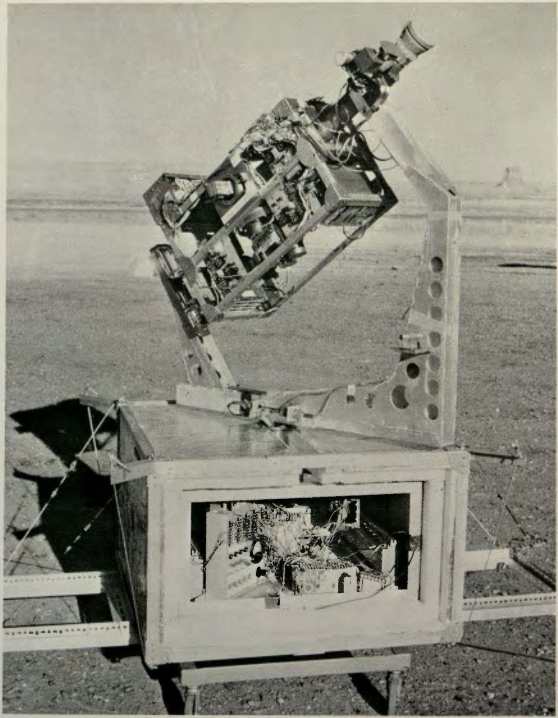
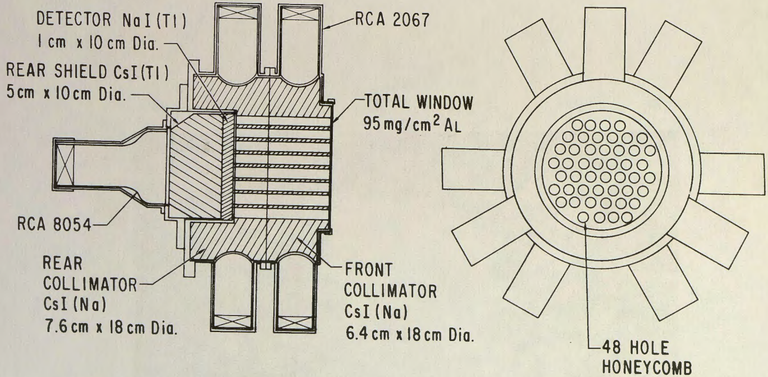


Figure 6. A Balloon Payload



SHIELD TUBES OPERATED IN COINCIDENCE		
EFFECTIVE AREA	=	34.6 cm
RESPONSE FWHM	=	5.4
TELESCOPE FACTOR	=	0.394 cm^2-ster.
SHIELD GEOMETRY	=	G_0 = 242 cm

ACTIVE HONEYCOMB DETECTOR - MOD 2

15 - 500 KeV

Figure 7. An Updated X-Ray Telescope.

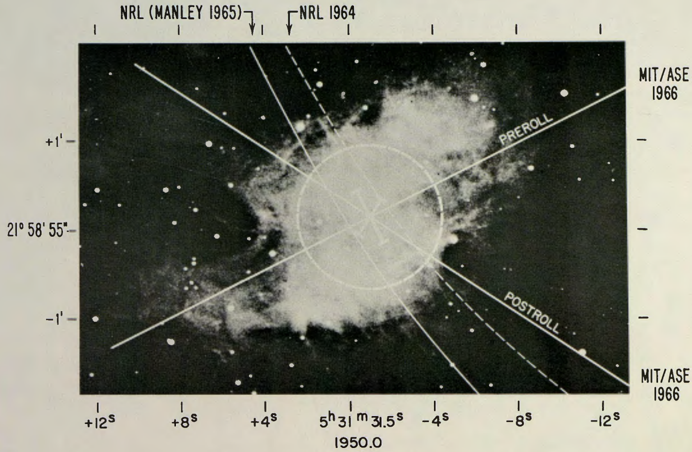


Figure 8. The Crab Nebula.

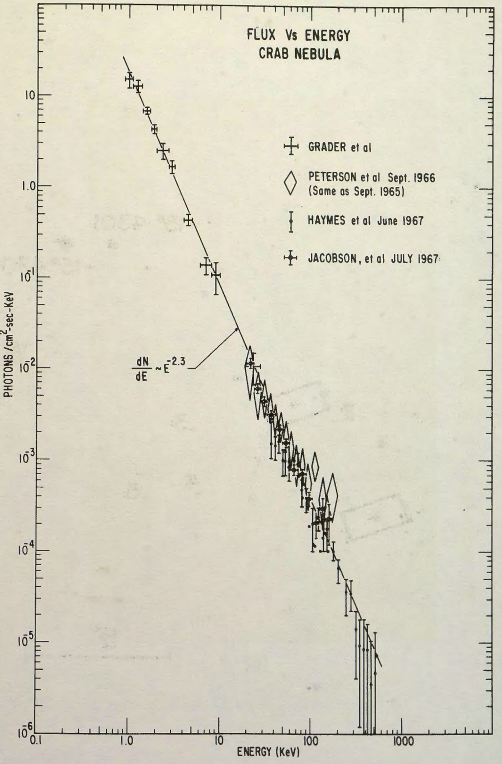


Figure 9. The Spectrum of the Crab Nebula.

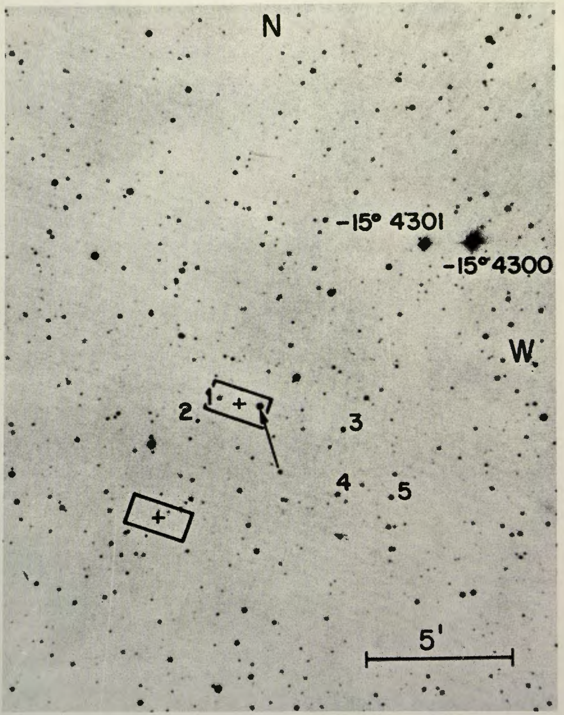


Figure 10. The Location of Sco XR-1.

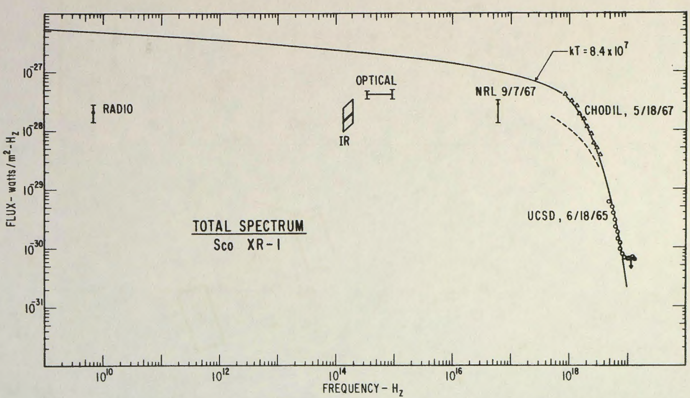


Figure 11. Total Spectrum of Sco XR-1.

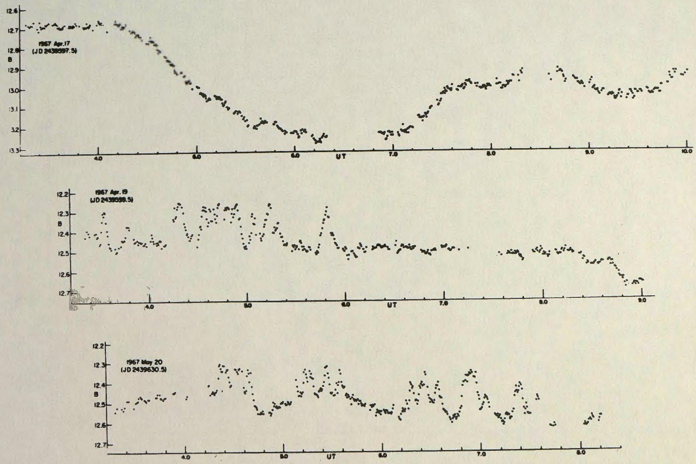


Figure 12. Optical Variation of Sco XR-1.

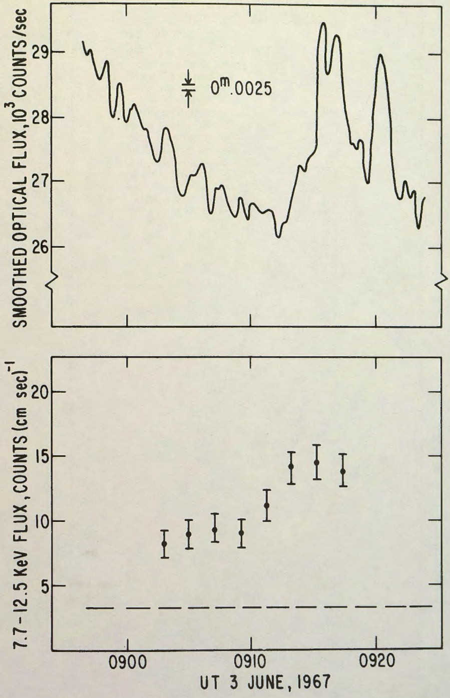


Figure 13. A Sco XR-1 Flare.

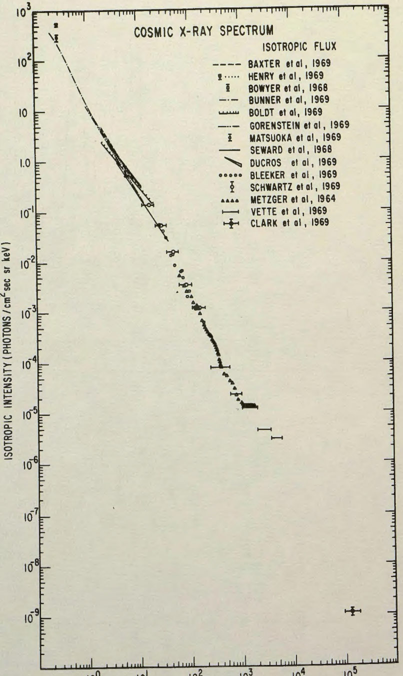


Figure 14. The Spectrum of Diffuse Cosmic X-Rays.

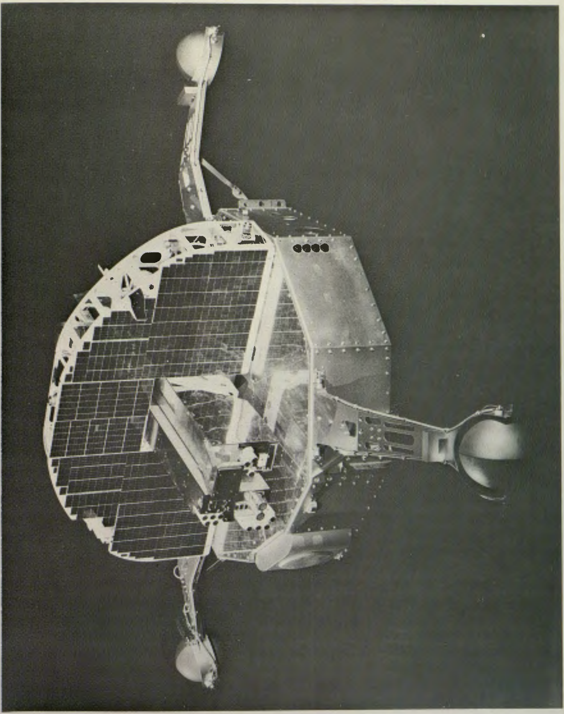


Figure 15. The OSO-III Satellite

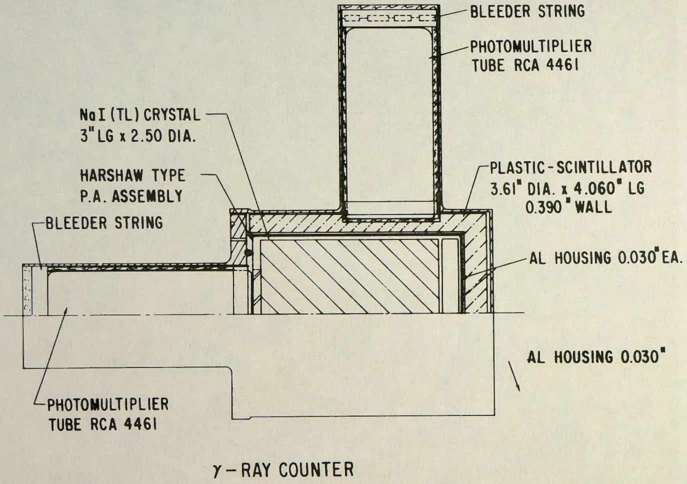


Figure 16. An Isotropic γ-Ray Spectrometer.

Figure 17. The High-Energy Astronomy Observatory.

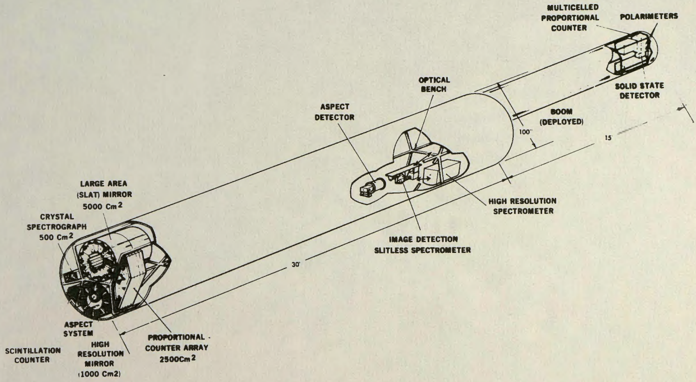


Figure 18. A Three-Axis Stabilized HEAO.